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(54) **Neural network prediction for radiographic x-ray exposures**

(57) A neural network prediction has been provided for predicting radiation exposure and/or Air-Kerma at a predefined arbitrary distance during an x-ray exposure; and for predicting radiation exposure and/or Air-Kerma area product for a radiographic x-ray exposure. The Air-Kerma levels are predicted directly from the x-ray exposure parameters. The method or model is provided to predict the radiation exposure or Air-Kerma for an arbitrary radiographic x-ray exposure by providing input variables (36,38,40) to identify the spectral characteristics of the x-ray beam, providing a neural net (32) which has been trained to calculate the exposure or Air-Kerma value, and by scaling (34) the neural net output by the calibrated tube efficiency (52), and the actual current through the x-ray tube and the duration of the exposure. The prediction for exposure/Air-Kerma further applies (50) the actual source-toobject distance, and the prediction for exposure/AirKerma area product further applies (54) the actual imaged field area at a source-to-image distance.

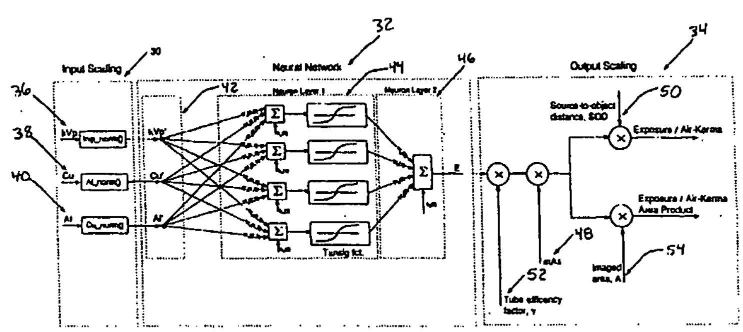

Figure 2

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Description

[0001] The present invention relates to x-ray system measurements, and, more particularly, to radiation exposure or Air-Kerma prediction for radiographic x-ray exposures.

[0002] Extensive scientific work has been done in the x-ray field measuring x-ray tube output in terms of radiation exposure (expressed in units of Roentgen)and Air-Kerma (expressed in units of Gray). This quantity is also known as the absorbed x-ray dose in air. Kerma stands for Kinetic Energy Released in the Medium and quantifies the amount of energy from the x-ray beam absorbed per unit mass. Radiation exposure is related to energy absorbed specifically in a given volume of air.

[0003] From a regulatory point of view, absorbed radiation dose or radiation exposure to the patient is often the key parameter of concern. Today, the general policy is to protect patients from unreasonable radiation dose, while still allowing the radiologist to obtain an image of acceptable quality. To control the level of exposure, new regulations, some already in effect in certain countries, require dose area product levels during an x-ray procedure to be reported. Furthermore, with ever-increasing concern for the quality of care, there is increased interest in regulatory evaluation of x-ray equipment.

[0004] Various methods have evolved to measure, predict, and control this x-ray quantity. In a current system, the "Dose Area Product" (reporting either radiation exposure or Air-Kerma) is measured directly with an ion chamber positioned in front of the collimator at the output of the x-ray tube. Alternatively, this quantity can also be predicted by monitoring x-ray techniques used in an exposure and, after calibrating radiation exposure measurements, then calculating and reporting the value.

[0005] Unfortunately, use of an ion chamber probe degrades the performance of the x-ray system, as the probe acts as an unnecessary attenuator in the x-ray beam. Additionally, the second method requires extensive calibrations that are not practical for many systems.

[0006] Therefore, due to the increasing demands in x-ray system performance, reduced sy em calibration needs, and increasing regulatory control, a new, predictive, non-invasive method for gathering reliable, non-falsifiable patient entrance exposure information, is desired.

[0007] The present invention provides for prediction of radiation exposure/Air-Kerma at a predefined patient entrance plane and the radiation exposure/Air-Kerma area product during a radiographic x-ray exposure. With the present invention, the need for the ion chamber and/or extensive system calibration are eliminated, as the radiation exposure/Air-Kerma levels are predicted directly from the x-ray exposure parameters. Additionally, the present invention satisfies known regulatory requirements in radiographic x-ray exposures.

[0008] In accordance with one aspect of the present invention, a method is provided to predict the radiation exposure or Air-Kerma for an arbitrary radiographic x-ray exposure by providing input variables to identify the spectral characteristics of the x-ray beam, providing a neural net which has been trained to calculate the exposure or Air-Kerma value, and by scaling the neural net output by the calibrated tube efficiency, the actual mAs and the actual source-to-object distance. In a further embodiment of the present invention, the radiation or Air-Kerma area product can be determined for a radiographic x-ray exposure by further applying image size information.

[0009] Accordingly, it is an object of the present invention to provide a radiation exposure/Air-Kerma prediction at a predefined patient entrance plane; and further to provide a radiation exposure/Air-Kerma area product prediction during a radiographic x-ray exposure. The present invention eliminates the use of a measuring probe that otherwise would have to be installed on the x-ray system, providing the advantages of reducing system cost and simplifying system packaging and power supplies. This invention also significantly reduces system calibrations needed for this reported measurement.

[0010] Other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

[0011] An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagfam of an x-ray imaging system; and

Fig. 2 is a neural net model for calculating the radiation exposure/Air-Kerma and the radiation exposure/Air-Kerma area product, relative to an x-ray imaging system such as is illustrated in Fig. 1, in accordance with the present invention.

[0012] The present invention proposes a neural network prediction of the radiation exposure/Air-Kerma at a predefined arbitrary distance during a radiographic x-ray exposure, and the radiation exposure/Air-Kerma area product for a radiographic x-ray exposure. Referring to Fig. 1, the prediction of the radiation exposure/Air Kerma is reported at a plane 10 defined by the Source-to-Object (SOD) distance shown. A high voltage generator 12 outputs the peak voltage (kVp) applied on an x-ray tube, and the current through the x-ray tube and duration of the exposure (mAs) to an x-ray

tube 14. X-rays emanate from focal spot 16, through Al and Cu filters 18 and collimator 20, generating x-ray photons indicated by arrows 22, which x-rays are transmitted through the object 24 under study, typically a human patient. An image is then output on image area 26 of imager 28.

[0013] Referring now to Fig. 2 and continuing with Fig. 1, the prediction of the radiation exposure/Air-Kerma and the radiation exposure/Air-Kerma area product is based upon an input scaling stage 30, a neural net model 32, and an output scaling stage 34.

[0014] The input scaling stage 30, is based on the peak voltage (kVp) information input at 36; the type of spectral filters, i.e., copper filter thickness, input at 38; and aluminum filter thickness input at 40.

[0015] The neural net model 32 is a two-layer neural network which has three input variables 42, four hidden-neurons 44, and one output neuron 46.

[0016] The output scaling function 34 uses values for current through the x-ray tube and duration of the exposure (mAs) input at 48; source to object 24 (patient) distance (SOD) input at 50; x-ray tube efficiency γ input at 52; and size of the imaged area, A, at the source-to-image distance (SID) input at 54. Specifically, as shown in Fig. 2, the prediction of radiation exposure/Air-Kerma at a predefined arbitrary distance during a radiographic x-ray exposure uses inputs 48 (mAs), 50 (SOD) and 52 (γ); and the prediction of radiation exposure/Air-Kerma area product for a radiographic x-ray exposure uses inputs 48 (mAs), 52 (γ), and 54 (SID).

[0017] The structure of the neural network according to the present invention is uniquely determined by two weighting matrices, W_1 and W_2, and two corresponding bias vectors, b_1 and b_2. There are four neurons in the first layer which all use the hyperbolic tangent sigmoidal transfer function. The second layer, or output layer, has just a single input linear transfer function neuron.

[0018] Continuing with Fig. 2, there is illustrated the input-output relationship of the input scaling stage for the present invention, where the inputs are:

RAD kVp	any legitimate kVp value for diagnostic system
Copper thickness	in mm
Aluminum thickness	in mm

which are used to construct the input vector as

$$\text{in} = [\text{kVp Cu Al}]^T$$

where T indicates a transposed vector.

[0019] Furthermore, in accordance with the present invention, there are three input normalization functions defined by the following relationships:

$$\text{kVp}' = \text{norm\_kVp(kVp)} =$$

$$\text{(kVp - kVp\_min)/(kVp\_max-kVp\_min)}$$

where

kVp_min = minimum kVp of system,

kVp_max = maximum kVp of system,

and

kVp = the actual kVp.

And

Cu' = norm_Cu(Cu) = Cu/Cu_max

where

Cu_max = maximum copper thickness, in mm, on system,

and

Cu = the actual thickness of copper filters, in mm, on the system.

And

Al' = norm_Al(Al)=(Al-Al_min)/(Al_max-Al_min)

where

Al_min = 1.0 mm

Al_max = maximum aluminum thickness, in mm, on system,

Al = the actual equivalent aluminum thickness, in mm, on the system.

The given normalization functions create the input vector to the neural network

$$in' = [kVp'\ Cu'\ Al']^T.$$

[0020] Continuing, the neural network coefficients comprise the weighting matrix from layer 1

$$W_1 = \begin{bmatrix} w_1(0,0) & w_1(1,0) & w_1(2,0) \\ w_1(0,1) & w_1(1,1) & w_1(2,1) \\ w_1(0,2) & w_1(1,2) & w_1(2,2) \\ w_1(0,3) & w_1(1,3) & w_1(2,3) \end{bmatrix},$$

the bias vector from layer 1

$$b_1 = [b_1(0)\ b_1(1)\ b_1(2)\ b_1(3)]^T,$$

the weighting matrix from layer 2

$$W_2 = [w_2(0)\ w_2(1)\ w_2(2)\ w_2(3)]^T,$$

and the bias for layer 2:

$$b_2 = b_2(0).$$

Therefore, the neural net output calculation becomes

$$E = W_2 * \mathrm{tansig}(W_1 * in' + b_1) + b_2$$

where the hyperbolic tangent sigmoid transfer function (tansig) is defined as

$$\mathrm{tansig}(x) = 2/(1+\exp(-2*x)) - 1.$$

The neural network coefficients for a fixed source-to-image distance and mAs, specifying the weighting matrices and bias vectors from layer 1 and 2, are obtained by training the neural net with a set of x-ray parameters, comprising kVp, aluminum thickness, copper thickness and resulting exposure or Air-Kerma values developed from either experimental data or theoretical models.

[0021] Since some variability may occur in the x-ray tube efficiency, the output is scaled by the Tube Efficiency Factor γ, which is calibrated at a single point before initial use.

[0022] For an arbitrary mAs, the output is scaled linearly with the ratio of the actual mAs value and the one used to train the neural network.

[0023] For an arbitrary source-to-object distance (SOD), the output is scaled by the square of the ratio of actual SOD and the SID used to train the neural network, according to the "R-square law".

[0024] The exposure or Air-Kerma area product is independent of the SOD. The area product requires that the source-to-image distance (SID) as well as the area of the exposed x-ray field at the SID are known. Those skilled in the art will know that on a conventional radiographic x-ray system, the SID is known from system calibration. The area of the exposed x-ray field can be predicted in accordance with the present invention by any suitable method, such as by calibrating the electric signal supplied to the horizontal and vertical collimator blades to their position on the x-ray image, or from a digital signal obtained directly from the x-ray image by a horizontal and vertical cross sectional analysis to determine blade positions.

[0025] From this, the exposure or Air-Kerma area product can be obtained by predicting the exposure of Air-Kerma at the SID for which the neural network was trained, and then scaling the result by the imaged area.

[0026] In accordance with the present invention, the exposure or Air-Kerma prediction is based on the information of kVp, mAs, and the type of spectral filters, i.e., copper filter thickness and aluminum filter thickness. The exposure/Air-Kerma is predicted for a specified source-to-object distance (SOD), and the exposure/Air-Kerma area product is predicted for a specified source-to-image distance (SID). For other distances, the "R-square law" is applied, by correcting with the square of the distance between tube and patient, or SOD.

[0027] The structure of the neural network according to the present invention is uniquely determined by two weighting matrices and two corresponding bias vectors. There are four neurons in the first layer which all use the hyperbolic tangent sigmoidal transfer function. The second layer, i.e., the output layer, has just a single input linear transfer function neuron.

Claims

1. A method for predicting radiation exposure or Air-Kerma during an arbitrary radiographic x-ray exposure, employing an x-ray tube to produce an x-ray beam, the x-ray tube having a calibrated tube efficiency, the method comprising the steps of:

   a) providing input variables to identify the spectral characteristics of the x-ray beam;
   b) providing a neural net to calculate a neural net output exposure value resulting from the input variables;
   c) training the neural net with a set of x-ray parameters to predict the radiation exposure or Air-Kerma for the x-ray exposure.

2. A method as claimed in claim 1 further comprising the step of providing input variables to identify intensity characteristics of the x-ray beam.

3. A method as claimed in claim 1 further comprising the step of scaling the neural net output exposure value by a calibrated tube efficiency to provide a first output result.

4. A method as claimed in claim 3 further comprising the step of scaling the first output result by an actual source-to-object distance measurement.

5. A method as claimed in claim 3 further comprising the step of scaling the neural net output exposure value by an actual intensity value to provide a second output result.

6. A method as claimed in claim 5 further comprising the step of scaling the second output result by an actual source-to-object distance measurement.

7. A method for predicting radiation exposure or Air-Kerma area product for an arbitrary radiographic x-ray exposure, employing an x-ray tube to produce an x-ray beam, the x-ray tube having a calibrated tube efficiency, the method comprising the steps of:

a) providing input variables to identify the spectral characteristics of the x-ray beam;
b) providing a neural net to calculate a neural net output exposure value resulting from the input variables;
c) training the neural net with a set of x-ray parameters to predict the radiation exposure or Air-Kerma for the x-ray exposure.

8. A method as claimed in claim 7 further comprising the step of scaling the neural net output exposure value by a calibrated tube efficiency to provide a first output result.

9. A method as claimed in claim 8 further comprising the step of scaling the first output result by an imaged field area at an actual source-to-image distance.

10. A method as claimed in claim 7 further comprising the step of scaling the neural net output exposure value by a value representing current through the x-ray tube and duration of the x-ray exposure to provide a third output result.

11. A method as claimed in claim 10 further comprising the step of scaling the third output result by an imaged field at an actual source-to-image distance.

12. A model for predicting radiation exposure or Air-Kerma and radiation exposure or Air-Kerma area product for an arbitrary radiographic x-ray exposure, employing an x-ray tube to produce an x-ray beam, the x-ray tube having a calibrated tube efficiency, the model comprising:

a) input variables to identify the spectral characteristics of the x-ray beam;
b) a neural net to calculate a neural net output exposure value resulting from the input variables;
c) a set of x-ray parameters applied to the neural net to predict the radiation exposure or Air-Kerma for the x-ray exposure.

13. A model as claimed in claim 12 wherein the input variables comprise three input variables.

14. A model as claimed in claim 12 wherein the set of x-ray parameters comprises at least one input normalization function, and a plurality of materials and thicknesses of the plurality of materials.

15. A model as claimed in claim 14 wherein the set of x-ray parameters further comprises experimental radiation exposure or Air-Kerma values.

16. A model as claimed in claim 14 wherein the set of x-ray parameters further comprises theoretical radiation exposure or Air-Kerma values.

17. A model as claimed in claim 14 wherein the set of x-ray exposure parameters further comprises intensity characteristics of the x-ray beam.

18. A model as claimed in claim 14 wherein the at least one input normalization function comprises peak voltage applied on the x-ray tube.

19. A model as claimed in claim 14 wherein the plurality of materials comprises at least aluminum and copper.

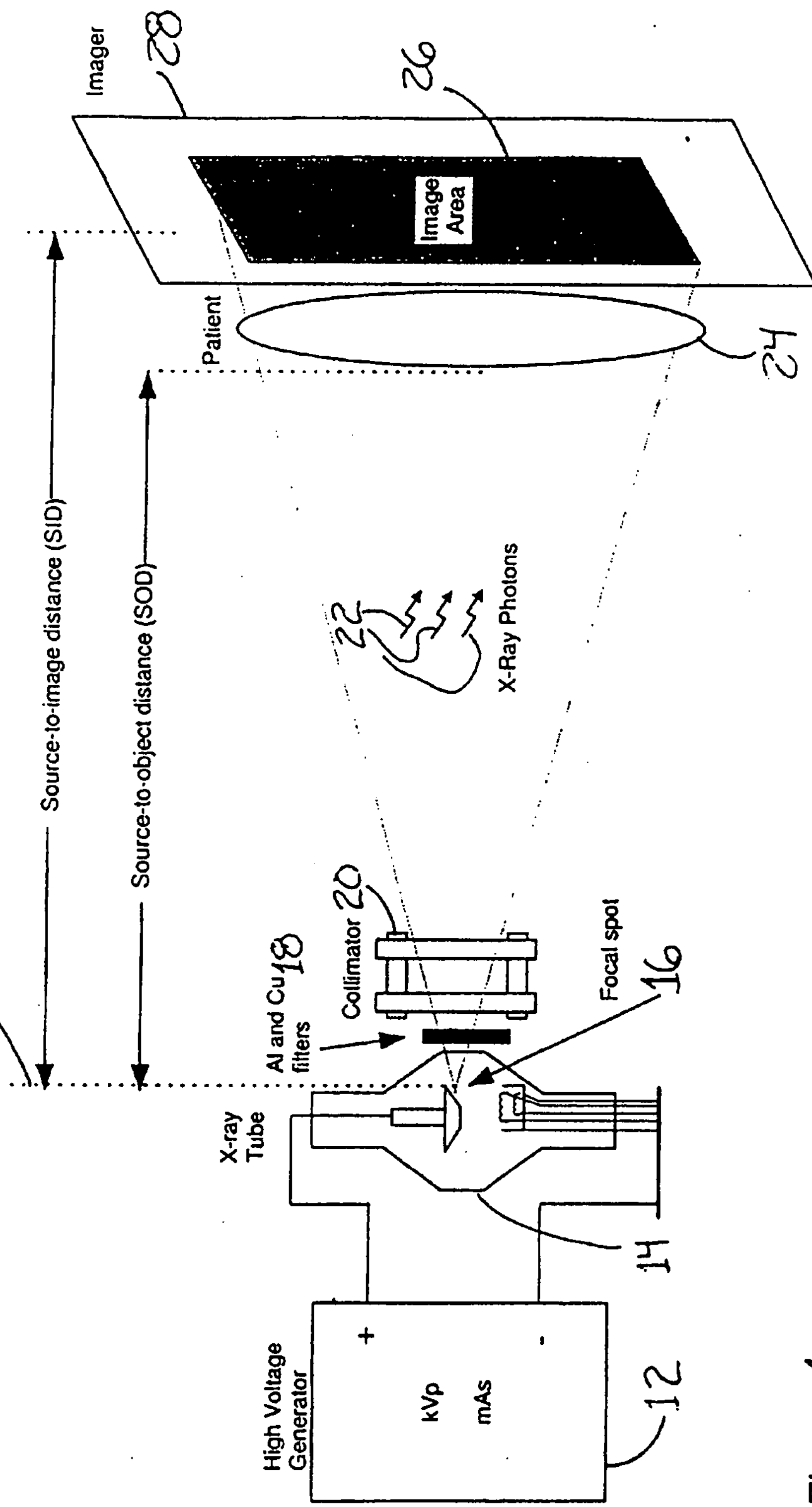
Imager
28
26
Image Area
Patient
24
Source-to-image distance (SID)
Source-to-object distance (SOD)
X-Ray Photons
22
Collimator
20
Al and Cu filters
18
Focal spot
16
10
X-ray Tube
14
High Voltage Generator
+
-
kVp
mAs
12

Figure 1

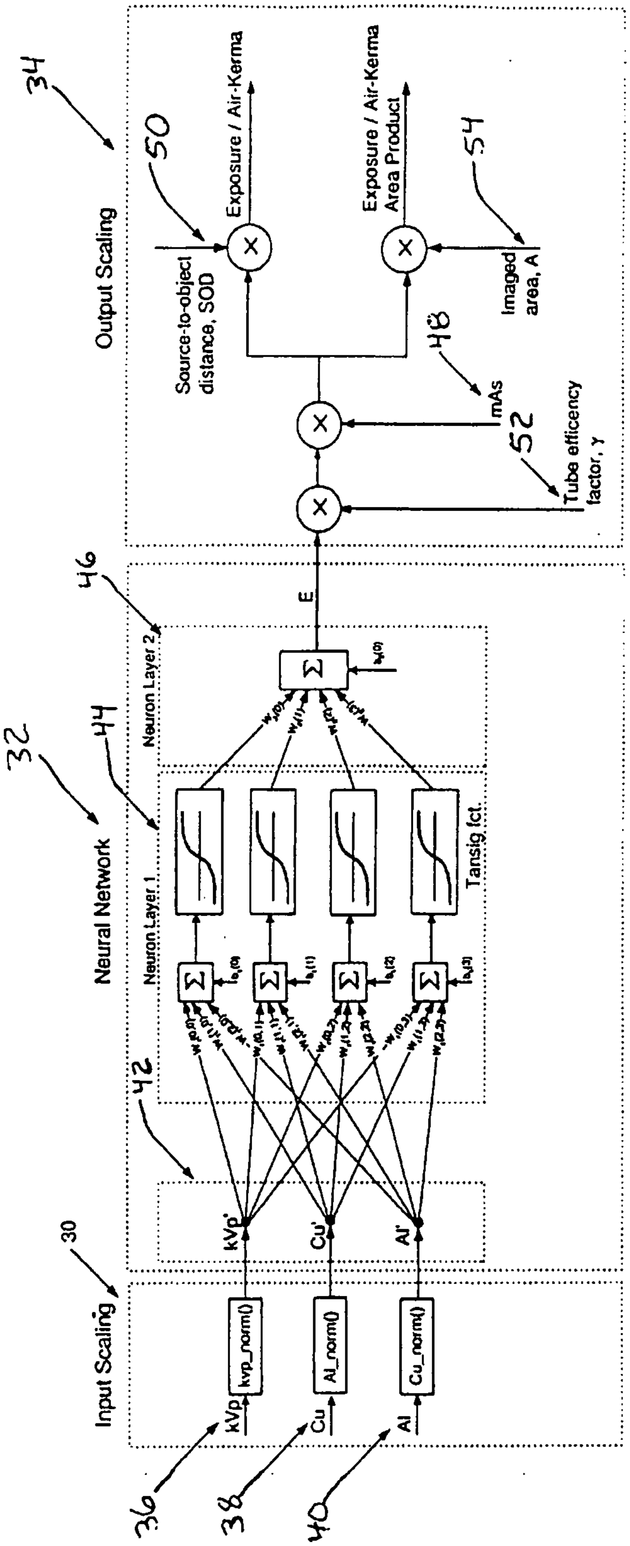
34
Output Scaling
50
Source-to-object distance, SOD
Exposure / Air-Kerma
Exposure / Air-Kerma Area Product
54
Imaged area, A
48
mAs
52
Tube efficency factor, γ
46
E
Neuron Layer 2
32
44
Neural Network
Neuron Layer 1
Tansig fct
42
30
Input Scaling
kVp
Cu
Al
kvp_norm()
Al_norm()
Cu_norm()
kVp'
Cu'
Al'
36
38
40

Figure 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 30 6158

DOCUMENTS CONSIDERED TO BE RELEVANT

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 July 2001	Oestreich, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

Application Number
EP 99 30 6158

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 July 2001	Oestreich, S

CATEGORY OF CITED DOCUMENTS

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04-07-2001

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